CHAPTER 10

ELECTROSTATIC DISCHARGE PROGRAM

The electrical noise generated in a radio or radar receiver is often confused with electrical noise generated external to the receiver and coupled into the receiver. The internally generated noise is the result of circuit deficiencies in the receiver itself, and can be eliminated by replacing the defective component or replacing the entire receiver. Electrical noise produced external to the receiver enters the receiver by various means. The noise causes interference in the receiver, as well as poor reception.

In early naval aircraft, electrical noise interference was not a major problem because there were fewer external sources of electrical noise. Receiver sensitivities were low, and the aircraft control components were manually operated. In today's aircraft, however, there are considerably more sources of externally generated electrical noise. The aircraft now contains numerous receivers with higher sensitivities, and the aircraft controls are operated by various electrical and/or mechanical devices. These devices include control surface drive motors, fuel and hydraulic boost pumps, ac inverters, and cabin pressurization systems. In addition, pulsed electronic transmitters, such as TACAN, radar, and IFF, can be sources of electrical noise interference. Listening to electrical noise interference in the output of a radio receiver can cause nervous fatigue in aircrew personnel. Electrical noise may also reduce the performance (sensitivity) of the receiver. For these reasons, electrical noise should be kept at the lowest possible level.

The overall objective of this chapter is to assist you in recognizing various types of electrical/electronic noise, their effects on radio and radar receivers, and what the electrostatic discharge program means to you as the work center supervisor. This chapter also provides you with information for keeping electrical noise interference as low as possible in electronic equipment aboard naval aircraft.

TYPES AND EFFECTS OF RECEIVER NOISE INTERFERENCE

Learning Objective: *Recognize the types and effects of radio noise, including natural and man-made interference.*

The types of electrical noise interference that enter aircraft receivers are broadly categorized as natural interference and man-made interference.

NATURAL INTERFERENCE

Radio interference caused by natural electrical noise is separated into three types: atmospheric static, precipitation static, and cosmic noise. Each type is discussed below.

Atmospheric Static

Atmospheric static is a result of the electrical breakdown between masses (clouds) of oppositely charged particles in the atmosphere. An extremely large electrical breakdown between two clouds or between the clouds and ground is called "lightning." Atmospheric static is completely random in nature, both as to rate of recurrence and as to intensity of individual discharges. Atmospheric static produces irregular popping and crackling in audio outputs and "grass" on visual output devices. Its effects range from minor annoyance to complete loss of receiver usefulness. Atmospheric interference is seldom of a crippling intensity at frequencies from 2 MHz to 30 MHz, but it can be annoying. Above 30 MHz, the noise intensity decreases to a very low level. At frequencies below 2 MHz, natural static is the principal limiting factor on usable receiver sensitivity.

The intensity of atmospheric static varies with location, season, weather, time of day, and the frequency to which the receiver is tuned. It is most intense at the lower latitudes, during the summer season, during weather squalls, and at the lower radio frequencies. Many schemes have been devised to minimize the effects of atmospheric static. However, the best technique is to avoid those frequencies associated with intense static, if possible.

Precipitation Static

Precipitation static is a type of interference that occurs during dust, snow or rain storms. The principal cause of precipitation static is the corona discharge of high-voltage charges from various points on the airframe. These charges may reach several hundred thousand volts before discharge occurs. The charge can be built up in two ways. First, an electrostatic field existing between two oppositely charged thunderclouds induces bipolar charges on the surfaces of the aircraft as it passes through the charged clouds. Second, a high unipolar charge on the entire airframe occurs from frictional charging by collision of atmospheric particles (low altitudes) or fine ice particles (high altitudes) with the aircraft's surface. The effects of corona discharge vary with temperature. The effects increase as altitude and airspeed increase. Doubling airspeed increases the effect by a factor of about 8; tripling airspeed increases the effect by a factor of about 27.

The effect of precipitation static is a loud hissing or frying noise in the audio output of a communication receiver and a corresponding "grass" indication on a visual output device. The radio frequency range affected by precipitation static is nearly the same as for atmospheric static. When present, precipitation interference is severe, and often totally disables all receivers tuned to the low- and medium-frequency bands.

Cosmic Noise

Cosmic noise is usually heard in the UHF band and above. However, it is occasionally heard at frequencies as low as 10 MHz. Cosmic noise is caused by the radiation of stars. Although its effect is generally unnoticed, at peaks of cosmic activity, cosmic noise interference could conceivably be a limiting factor in the sensitivity of navigational and height-finder radar receivers.

MAN-MADE INTERFERENCE

Man-made interference is generally categorized according to the spectrum of its influence, such as broadband and narrow band. Each type of man-made interference is discussed below.

Broadband Interference

Broadband interference is generated when the current flowing in a circuit is interrupted or varies at a rate that departs radically from a sinusoidal rate. A current whose waveform is a sine wave is capable of interfering only at a single frequency. Any other waveform contains harmonics of the basic frequency. The steeper the rise or fall of current, the higher the upper harmonic frequency will be. A perfect rectangular pulse contains an infinite number of odd harmonics of the frequency represented by its pulse recurrence rate. Typical types of electrical disturbances that generate broadband interference are electrical impulses, electrical pulses, and random noise signals.

For purposes of this discussion, *impulse* is the term used to describe an electrical disturbance, such as a switching transient that is an incidental product of the operation of an electrical or electronic device. The impulse recurrence rate may or may not be regular. *Pulse* is the term used to describe an intentional, timed, momentary flow of energy produced by an electronic device. The pulse recurrence rate is usually regular.

Switching transient or impulses result from the make or break of an electrical current. They are extremely sharp pulses. The duration and peak value of these pulses depend upon the amount of current and the characteristics of the circuit being opened or closed. The effects are sharp clicks in the audio output of a receiver and sharp spikes on an oscilloscope trace. The isolated occasional occurrence of a switching transient has little or no significance. However, when repeated often enough and with sufficient regularity, switching transients are capable of creating intolerable interference to audio and video circuits, thus degrading receiver performance. Typical sources of sustained switching transients are ignition timing systems, commutators of dc motors and generators, and pulsed navigational lighting.

Pulse interference is normally generated by pulsed electronic equipment. This type of interference is characterized by a popping or buzzing in the audio output device and by noise spikes on an oscilloscope. The interference level depends upon the pulse severity, repetition frequency, and the regularity of occurrence. Pulse interference can trigger beacons and IFF equipment and cause false target indications on the radar screens. In certain types of navigational beacons, these pulses cause complete loss of reliability.

Random noise consists of impulses that are of irregular shape, amplitude, duration, and recurrence rate. Normally, the source of the random noise is a variable contact between brush and commutator bar or slip ring, or an imperfect contact or poor isolation between two surfaces.

Narrow-Band Interference

Narrow-band interference is almost always caused by oscillators or power amplifiers in receivers and transmitters. In a receiver, the cause is usually a poorly shielded local oscillator stage. In a transmitter, several of the stages could be at fault. The interference could be at the transmitter operating frequency, a harmonic of its operating frequency, or at some spurious frequency. A multichannel transmitter that uses crystal-bank frequency synthesizing circuits can produce interference at any of the frequencies present in the synthesize. Narrow-band interference in a receiver can range in severity from an annoying heterodyne whistle in the audio output to the complete blocking of received signals. Narrow-band interference affects single frequencies or spots of frequencies in the tuning range of the affected receiver.

SOURCES OF ELECTRICAL NOISE

Learning Objective: *Recognize the various sources of electrical noise and the operating characteristics of each.*

Any circuit or device that carries a varying electrical current is a potential source of receiver interference. The value of the interference voltage depends upon the amount of voltage change. The frequency coverage depends upon the abruptness of the change. The principal sources of man-made interference in aircraft include rotating electrical machines, switching devices, pulsed electronic equipment, propeller systems, receiver oscillators, nonlinear elements, and ac power lines. Each of these sources of noise is discussed in the following sections.

ROTATING ELECTRICAL MACHINES

Rotating electrical machines are a major source of receiver interference because of the large number of electric motors used in the aircraft. Rotating electrical machines used in aircraft may be divided into three general classes: dc motors, ac motors and generators, and inverters.

DC Motors

Modern aircraft use dc motors in great numbers, such as in flight control actuators, armament actuators, and flight accessories. Most electronic equipment on the aircraft include one or more dc motors for driving cycling mechanisms, compressor pumps, air circulators, and antenna mechanisms. Each of these motors can generate voltages capable of causing radio interference over a wide band of frequencies. Types of interfering voltages generated by dc motors areas follows:

- Switching transients generated as the brush moves from one commutator bar to another (commutation interference)
- Random transients produced by varying contact between the brush and the commutator (sliding contact interference)
- Audio-frequency hum (commutator ripple)
- Radio frequency and static charges built up on the shaft and the rotor assembly

The dc motors used in aircraft systems are of three general types: the series- wound motor, the shunt-wound motor, and the permanent-magnet (PM) motor. The field windings of both series- and shunt-wound motors afford some filter action against transient voltages generated by the brushes. The PM motor's lack of such inherent filtering makes it a very common source of interference. The size of a dc motor has little bearing upon its interference generating characteristics. The smallest motor aboard the aircraft can be the worst offender.

AC Generators and Motors

The output of an ideal alternating-current generator is a pure sine wave. A pure sine-wave voltage is incapable of producing interference except at its basic frequency. However, a pure waveform is difficult to produce, particularly in a small ac generator. Nearly all types of ac generators used in naval aircraft are potential sources of interference at frequencies other than the output power frequency. Interference voltages are produced by the following sources:

- Harmonics of the power frequency. Generally, the harmonics are caused by poor waveform.
- Commutation interference. This condition originates in a series-wound motor.

- Sliding-contact interference. This condition originates in an alternator and in a series-wound motor.

Generally, an ac motor without brushes does not create interference.

Inverters

An inverter is a dc motor with armature taps brought out to slip rings to supply an ac voltage. The ac output contains some of the interference voltages generated at the dc end, as well as the brush interference at the ac end of the inverter.

SWITCHING DEVICES

A switching device makes abrupt changes in electrical circuits. Such changes are accompanied by transients capable of interfering with the operation of radio and other types of electronic receivers. The simple manual switch (occasionally operated) is of little consequence as a source of interference. Examples of switching devices (frequently operated) capable of causing appreciable or serious interference are the relay and the thyratron.

Relays

A relay is an electromagnetically operated remote-control switch. Its main purpose is to switch high-current, high-voltage, or other critical circuits. Since the relay is used almost exclusively to control large amounts of power with relatively small amounts of power, the relay is always a potential source of interference. This is especially true when the relay is used to control an inductive circuit. Relay-actuating circuits should not be overlooked as possible interference sources. Even though the actuating currents are small, the inductances of the actuating coils are usually quite high. It is not unusual for the control circuit of a relay to produce more interference than the controlled circuit.

Thyratrons

A thyratron is a gas-filled, grid-controlled, electronic switching tube used mainly in radar modulators. The current in a thyratron is either ON or OFF; there is no in-between. Since the time required to turn a thyratron ON is only a few microseconds, the current waveform in a thyratron circuit always has a sharp leading edge. As a result, the waveform is rich in radio interference energy. The voltage and peak power in a radar modulator are usually very high, and the waveforms are intentionally made as sharp and flat as possible. Although these factors are essential for proper radar operation, they also increase the production of interference energy.

PULSED ELECTRONIC EQUIPMENT

Pulse interference is generated by pulsed electronic equipment. Types of systems that fall within this category include radar, beacons, transponders, and coded-pulse equipment.

Radar

In radar equipment, range resolution depends largely on the sharpness of the leading and trailing edges of the pulse. The ideal pulse is a perfect square wave. Target definition is also dependent on the narrowness of the pulse. Both the steepness and the narrowness of a pulse determine the number and amplitudes of harmonic frequencies. With respect to the shape of a radar pulse, the better the radar is working, the greater the interference it is capable of producing. Most of the interference is produced at frequencies other than those leaving the radar antenna, except in receivers operating with the radar band.

Radar interference at frequencies below the antenna frequency severely affects all receivers in use. Principal sources of such interference are the modulator, pulse cables, and transmitter.

Transponders, Coded-Pulse Equipment, and Beacons

This group includes IFF, beacons, TACAN, teletype, and other coded-pulse equipment. The interference energy produced by this group is the same as that produced by radar-pulsing circuits. The effects of this interference energy are lessened because the equipment is usually self-contained in one shielded case, and uses lower pulse power. The effects are increased because the radiating frequencies are lower, which allows fundamental frequencies and harmonics to fall within the frequency bands used by other equipment. Each piece of equipment is highly capable of producing interference outside the aircraft where it can be picked up by receiver antennas.

PROPELLER SYSTEMS

Propeller systems, whether hydraulically or electrically operated, are potent generators of radio interference. The sources of interference include propeller pitch control motors and solenoids, governors and associated relays, synchronizers and associated relays, deicing timers and relays, and inverters for synchro operation.

Propeller control equipment generates clicks and transients as often as 10 per second. The audio frequency envelope of commutator interference varies from about 20 to 1000 Hz. The propeller deicing timer generates intense impulses at a maximum rate of about 4 impulses per minute.

Values of current in the propeller system are relatively high; consequently, the interference voltages generated are severe. They are capable of producing moderate interference at frequencies below 100 kHz and at frequencies above 1 MHz. However, the interference voltages can cause severe interference at intermediate frequencies.

RECEIVER OSCILLATORS

Either directly or through frequency multipliers or synthesizers, the local oscillator in a superheterodyne receiver generates an RF signal at a given frequency. The local oscillator signal is mixed with another RF signal to produce an intermediate frequency (IF) signal. Depending on receiver design, the frequency of the local oscillator signal is either above or below the frequency of the RF signal by a frequency equal to the IF.

The amount of interference leaving the receiver through its antenna is roughly proportional to the ratio of the tuned input frequency to the intermediate frequency. For any tuning band on the receiver, oscillator leakage is highest at the low end of the band. Also, the lower the intermediate frequency, the greater the leakage probability.

Although the receiver antenna is the principal outlet of oscillator leakage, leakage can occur from other points. Any path capable of introducing interference into a receiver is also capable of carrying internally generated interference out of the receiver. The paths of entry are discussed in more detail later in this chapter.

Oscillator leakage from a single communications receiver in an aircraft is not likely to be a direct source of interference, except in a very large aircraft where two or more frequencies in the same band are used simultaneously. However, high-order harmonics of the oscillator frequency can become troublesome in the VHF band and above.

Oscillator leakage from a swept-tuning receiver can produce interference in any receiver aboard the aircraft. This is done directly (on harmonics) or by nonlinear mixing, as shown in the following example:

- Receiver A, operating at a frequency of 2100 kHz, with an IF of 500 kHz, has oscillator leakage at 2600 kHz (or 1600 kHz).
- Receiver B, operating at 150 MHz, with an IF of 10 MHz, has oscillator leakage at 160 MHz (or 140 MHz).
- Receiver C, sweeping a frequency band from 200 to 300 MHz, with an IF of 30 MHz, has oscillator leakage across the band 170 to 270 MHz (or 230 to 330 MHz).

Each receiver is capable of interfering with the other receivers at the oscillator frequency and its harmonics. In addition, with the presence of a nonlinear detector, the leakage signals from the three receivers can be mixed and interfere with the following frequencies:

- Receivers A and B, after nonlinear mixing, can produce interference at 160±2.6 MHz.
- Receivers A and C can similarly produce interference at any frequency from 200±2.6 to 300 ±2.6 MHz; receivers B and C between 200 ±160 to 300±160 MHz.

NONLINEAR ELEMENTS

A nonlinear element is a conductor, semiconductor, or solid-state device whose resistance or impedance varies with the voltage applied across it. Consequently, the resultant voltage is not proportional to the original applied voltage. Typical examples of nonlinear elements are metallic oxides, certain nonconducting crystal structures, semiconductor devices, and electron tubes. Nonlinear elements that could cause radio interference in aircraft systems are overdriven semiconductors and vacuum tubes, oxidized or corroded joints, cold-solder joints, and unsound welds.

In the presence of a strong signal, a nonlinear element acts like a detector or mixer. It produces sum and difference frequencies and any harmonics from the signal applied to it. These spurious frequencies are called "external cross-modulation." These spurious frequencies (sum, difference, and harmonics) can be expected to cause interference problems when the combined product of their field strengths exceed 1 millivolt.

A common example of this action is the entry of a strong off-frequency RF voltage into the mixer stage of a superheterodyne receiver. By the time the interfering signal has passed through the preselector stages of the receiver, it has undergone distortion by clipping. Therefore, the interfering signal is essentially a rectangular wave that is rich in harmonics. Frequency components of the wave beat both above and below the local oscillator frequency and its harmonics, and produce, at the output of the mixer, signals that are acceptable to the IF amplifier.

POWER LINES

Alternating current power sources have already been briefly discussed as broadband interference. Even though they are conducting a nearly sinusoidal waveform, ac signals on power lines are capable of interfering with audio signals in receivers. In such cases, only the power-line frequency appears. However, where multiple sources of ac power are present, these signals are capable of being mixed in the same manner as discussed under receiver oscillators. Sum and difference frequencies appear.

In at-powered equipment, ac hum can appear at the power frequency or at the rectification ripple frequency. The rectification ripple frequency is twice the power frequency times the number of phases. Normally, aircraft systems use only single- and three-phase sources at a nominal 400 Hz. Full-wave rectification with single-phase 400-Hz power gives a ripple frequency of 800 Hz. A three-phase source would give a 2400 Hz ripple. This ripple produces interference varying from annoyance to complete unreliability of equipment, depending upon the severity and its coupling to susceptible elements.

INTERFERENCE COUPLING

Learning Objective: *Identify the various types of electrical interference caused by coupling, and recognize the means used to reduce the interference.*

Openings in the outer shields of equipment are necessary for the entrance of power leads, control leads, mechanical linkages, ventilation, and antenna leads. Interference entering these openings is amplified by various amounts, depending upon the point of entry into the equipment's circuits. Coupling between the entry path and the sensitive points of the receiver can be in any form.

CONDUCTIVE COUPLING

Interference is often coupled from its source to a receiver by metallic conduction. Normally, this is done by way of mutual impedance, as shown in figure 10-1. Note in the figure that A is the power source, B the receiver, and C the interference source. The interference is maximum at the interference source (C), and attenuates rapidly to a relatively low value at the battery (A). This occurs because of the very low impedance of the battery. It is apparent from the size of the arrows that the nearer the power tap of the receiver (B) to the interference source (C), the greater the amplitude of interfering current in the BC loop.

INDUCTIVE-MAGNETIC COUPLING

Every current-carrying conductor is surrounded by a magnetic field whose intensity variations are faithful reproductions of variations in the current in the conductor. When another parallel conductor is cut by the lines of force of this field, the conductor has a current induced into it. The amplitude of the induced current depends upon the following factors:

- The strength of the current in the first conductor
- The nearness of the conductors to each other
- The angle between the conductors
- The length through which the conductors are exposed to each other

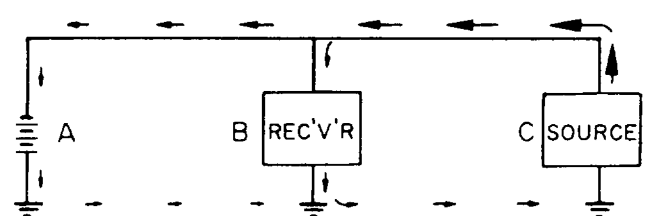

Figure 10-1.-Path of conducted interference.

The amount of the variation in the current that directly affects variation in the magnetic field surrounding the conductor depends upon the nature of the current. When the conductor is a power lead to an electric motor, all the frequencies and amplitudes associated with broadband interference are present in the magnetic field. When the lead is an ac power lead, a strong sinusoidal magnetic field is present. When the lead is carrying switched or pulsed currents, extremely complex broadband variations are present. As the magnetic field cuts across a neighboring conductor, a voltage replica of its variation is induced into the neighboring wire. This causes a current to flow in the neighboring wire. When the neighboring wire leads to a sensitive point in a susceptible receiver, serious interference with that receiver's operation can result. Similarly, a wire carrying a steady, pure dc current of high value sets up a magnetic field capable of affecting the operation of equipment whose operation is based upon the earth's magnetic field.

Shielding a conductor against magnetic induction is both difficult and impractical. Nonferrous shielding materials have little or no effect upon a magnetic field. Magnetic shielding that is effective at low frequencies is prohibitively heavy and bulky.

In aircraft wiring, the effect of induction fields should be minimized. This can be done by use of the proper spacing and coupling angle between wires. The degree of magnetic coupling diminishes rapidly with distance. Interference coupling is least when the space between active and passive leads is at a maximum, and when the angle between the leads approaches a right angle.

INDUCTIVE-CAPACITIVE COUPLING

Capacitive (electric) fields are voltage fields. Their effects depend upon the amount of capacitance existing between exposed portions of the noisy circuit and the noise-free circuit. The power transfer capabilities are directly proportional to frequency. Thus, high-frequency components are more easily coupled to other circuits. Capacitive coupling is relatively easy to shield out by placing a grounded conducting surface between the interfering source and the susceptible conductor.

COUPLING BY RADIATION

Almost any wire in an aircraft system can, at some particular frequency, begin to act like an antenna through a portion of its length. Inside an airframe, however, this occurs only at very high frequencies. At high frequencies, all internal leads are generally well shielded against pickup of moderate levels of radiated energy. Perhaps the only cases of true inside-the-aircraft radiation at HF and below occur in connection with unshielded or inadequately shielded transmitter antenna leads.

COMPLEX COUPLING

Some examples of interference coupling involve more than one of the types (conduction, induction, or radiation) just discussed. When more than one coupling occurs simultaneously, corrective actions, such as bonding, shielding, or filtering, used to correct one type of coupling can increase the coupling capabilities of another type of coupling. The result may be an increase in the transfer of interference. For example, an unbended, unfiltered dc motor can transfer interference to a sensitive element by conduction, inductive coupling, capacitive coupling, and by radiation. Some frequencies are transmitted predominately by one form of coupling and some frequencies by others. At still other frequencies, all methods of transmission are equally effective. On the motor used in the example above, bonding almost always eliminates radiation from the motor shell. It also increases the intensity in one of the other methods of transmission, usually by conduction. The external placement of a low-pass filter or a capacitor usually reduces the intensity of conducted interference. At the same time, it may increase the radiation and induction fields. This occurs because the filter appears to interference voltages to be a low-impedance path across the line. Relatively high interference currents then flow in the loop formed between the source and the filter. For complex coupling problems, multiple solutions may be required to prevent the interference.

RADIO INTERFERENCE REDUCTION COMPONENTS

Learning Objective: *Recognize various methods and components used to reduce radio interference caused by electrical noise.*

Radio interference reduction at the source maybe accomplished to varying degrees by one or more of the following methods: short circuiting, dissipation, open circuiting, or a combination of all three.

Discrete components are normally used to achieve interference reduction at the source. Capacitors, resistors, and inductors are used to short circuit, dissipate, and open circuit the interference, respectively.

CAPACITORS

Short circuiting of interference is done by using capacitors connected across the source. The perfect capacitor looks like an open circuit to dc or the power frequency, and progressively as a shoft circuit to ac as the frequency is increased.

Function

The function of a capacitor in connection with radio interference filtering is to provide a low-impedance, radio-frequency path across the source. When the reactance of the capacitor is lower than the impedance of the power lines to the source, high-frequency voltages see the capacitor as a shorter path to ground. The capacitor charges to the line voltage. It then tends to absorb transient rises in the line voltage and to provide energy for canceling transient drops in the line voltage.

Limitations

The efficiency of a perfect capacitor in bypassing radio interference increases indirect proportion to the frequency of the interfering voltage, and in direct proportion to the capacitance of the capacitor. All capacitors have both inductance and resistance. Any lead for connecting the capacitor has inductance and resistance as a direct function of lead length and inverse function of lead diameter. Some resistance is inherent in the capacitor itself in the form of dielectric leakage. Some inductance is inherent in the capacitor, which is usually proportional to the capacitance.

The effect of the inherent resistance in a high-grade capacitor is negligible as far as its filtering action is concerned. The inherent inductance, plus the lead inductance, seriously affects the frequency range over which the capacitor is useful. The bypass value of a capacitor with inductance in series varies with frequency.

At frequencies where inductive reactance is much less than capacitive reactance, the capacitor looks very much like a pure capacitance. As the frequency approaches a frequency at which the inductive reactance is equal to the capacitive reactance, the net series reactance becomes smaller until the resonant frequency, a point of zero impedance, is reached. At this point, maximum bypass action occurs. At frequencies above the resonant frequency, the inductive reactance becomes greater than the capacitive reactance. The capacitor then exhibits a net inductive reactance, whose value increases with frequency. At frequencies much higher than the resonant frequency, the value of the capacitor as a bypass becomes lost.

The frequency at which the reversal of reactance occurs is controlled by the size of the capacitor and the length of the leads. For instance, the installation of a very large capacitor frequently requires the use of long leads. As an example of the influence of lead length upon the bypass value of a capacitor, the following data is presented to a typical 4-microfarad capacitor whose inherent inductance is 0.0129 henrys:

LEAD LENGTH	CROSSOVER FREQUENCY
1 inch	0.47 MHz
2 inches	0.41 MHz
3 inches	0.34 MHz
4 inches	0.30 MHz
6 inches	0.25 MHz

Note that for the 4-µF capacitor, each additional inch of lead causes the capacitance-inductance crossover point to be reduced.

In figure 10-2, notice the capacitance-to-inductance crossover frequencies for various lead lengths of a 0.05 microfarad capacitor. Also, notice the difference in the crossover frequencies for the 3-inch lead for the 4-µF capacitor, discussed above, and for the 3-inch lead for the 0.05-capacitor referenced in figure 10-2.

Coaxial Feedthrough Capacitors

Coaxial feedthrough capacitors are available with capacitances from 0.00005 to about 2 µF. These capacitors work well up to frequencies several times those at which capacitors with leads become useless.

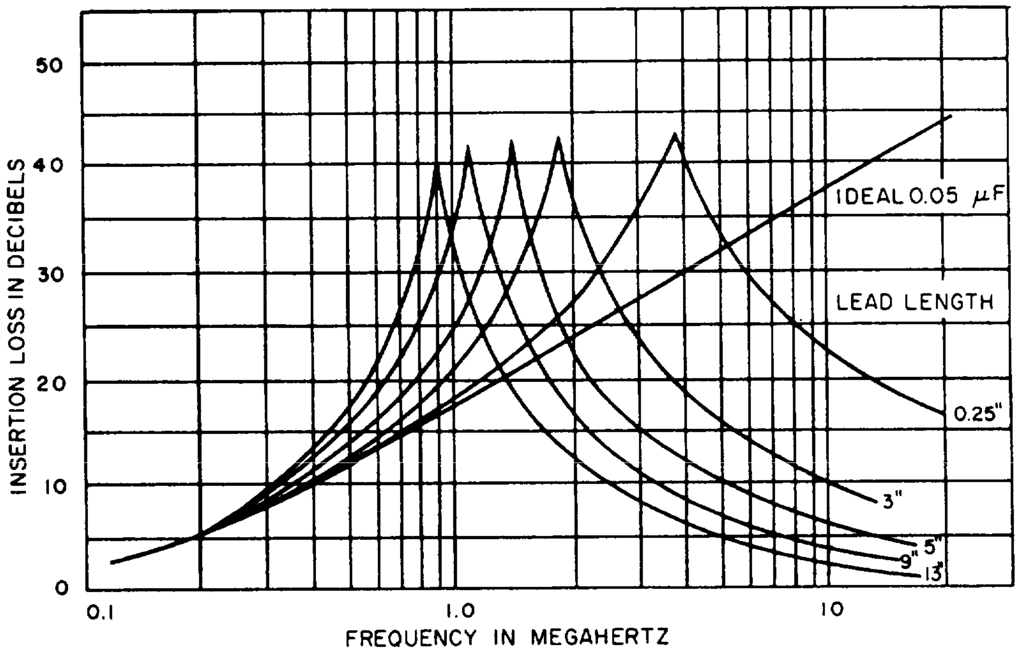

Figure 10-2.-Crossover frequency of a 0.05-microfarad capacitor with various lead lengths.

The curves in figure 10-3 compare the bypass value of a feedthrough capacitor of 0.05 μF with that of a hypothetically perfect capacitor of the same capacitance. The feedthrough capacitor differs from the capacitor with leads in that the feedthrough capacitor type forms a part of both the circuit being filtered and the shield used to isolate the filtered source. Lead length has been reduced to zero. The center conductor of the feedthrough capacitor must carry all the current of the filtered source and must have an adequate current rating to ensure against dc loss or power frequency insertion loss. The internal

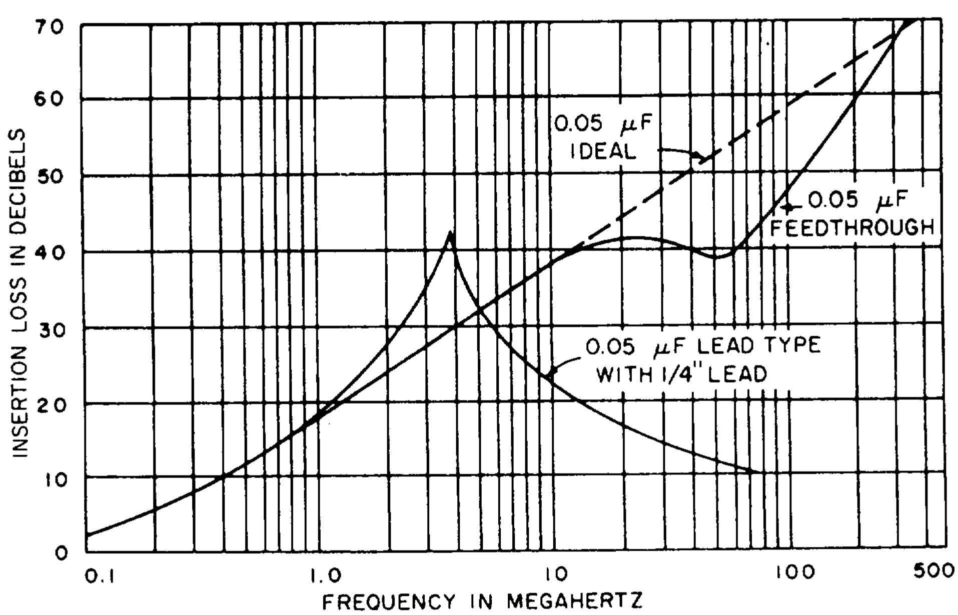

Figure 10-3.-Crosover frequency of a 0.05-microfarad feedthrough capacitor.

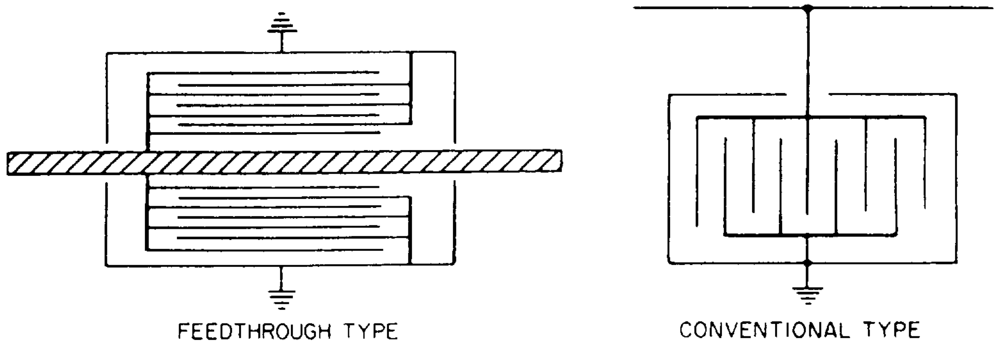

Figure 10-4.-Internal construction of feedthrough and conventional capacitor.

constructions of feedthrough and conventional capacitors are shown in figure 10-4. Notice the differences in the two types.

Selection of Capacitors

Capacitors used for filtering circuits in aircraft should be selected for characteristics such as physical size, high temperature and humidity tolerances, and physical ruggedness. The capacitors should have an adequate voltage rating (at least twice that of the circuit to be filtered), and should be installed with minimum lead length.

Application of Capacitive Filters

Every circuit carrying an unintentionally varying voltage or current capable of causing radio interference should be bypassed to ground by suitable capacitors. When the nature of the variations are such that interference is caused at both high and low frequencies, a capacitor should be chosen and installed to provide an adequate insertion loss at the lowest frequency where interference exists. When the overall capacitance required at low frequency provides inadequate insertion loss at high frequencies, it should be bridged in the shortest and most direct manner possible by a second capacitor.

A capacitive filter should be installed as near as possible to the actual source of interference. Lead length should be held to an absolute minimum for two reasons. First, the lead to the capacitor carries interference that must not be allowed to radiate. Second, the lead has inductance that tends to lower the maximum frequency for which the capacitor is an effective bypass.

To the extent possible, a filter capacitor should be installed to make use of any element of the filtered circuit that provides a better filtering action. Figures 10-5, 10-6, and 10-7 illustrate proper use of filter capacitors.

Capacitive Filtering in an AC Circuit

The radio interference generated in slip ring ac motors and generators is a transient caused by sliding contacts plus high-frequency energy from other internal sources. For this reason, filtering should be aimed at reducing high-frequency and very-high-frequency noise components with the use of low-capacitance, high-grade capacitors. Wherever possible, feedthrough capacitors should be used. Capacitances should be chosen low enough in value to represent a high impedance at the power frequency and to avoid resonance with the internal inductances of the filtered unit. Voltage ratings should be at least twice the peak voltage across the capacitors.

In a four-wire electrical system, the neutral lead carries all three phases; a large quantity of the third harmonic of the power frequency is present. This

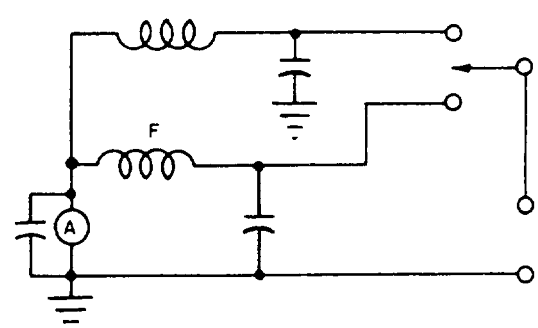

Figure 10-5.-Capacitive filtering of a reversible dc series motor.

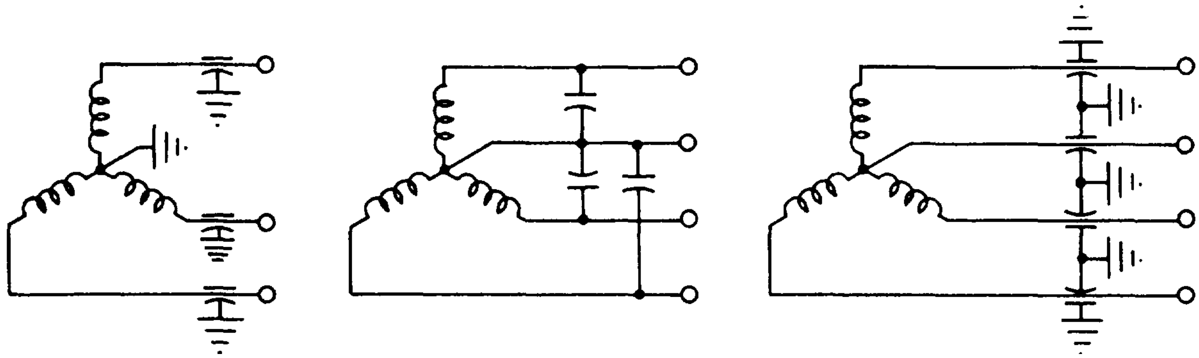

Figure 10-6.-Capacitive filtering of a three-phase attenuator.

frequency must be considered in setting capacitance limits and in filtering the return lead. Normal values of capacitance for filtering 400-hertz leads vary from 0.05 to 0.1 μF.

Capacitive Filtering of Switching Devices

Normally, a capacitor should not be used by itself as a filter on a switch in a dc system. In the open position, the capacitor bridging the switch assumes a charge equal to the line voltage. When the switch closes, the capacitor discharges at such a rapid rate that it generates a transient energy, whose interference value exceeds that caused by the opening of the unfiltered circuit. The capacitor across a switch should have enough series resistance to provide a slow discharge when the capacitor is shorted by the switch.

RESISTIVE-CAPACITIVE FILTERS

A resistive-capacitive (RC) filter is an effective arc and transient absorber. The RC filter reduces interference in two ways—by changing the waveform of transients and by dissipating transient energy. Figure 10-8 shows how an RC filter is connected across a switch.

Without the RC filter, the voltage appearing across the switch at the instant the switch is opened is equal to the sum of the line voltage and an inductive voltage of the same polarity. The amplitude of the inductive surge depends upon the inductance of the line and the amplitude of the closed-circuit current.

When the sum of the voltages appearing across the switch is great enough, arcing occurs. When the capacitance is large enough, the capacitor absorbs sufficient transient energy to reduce the voltage to below arcing value. During the charging time of the capacitor, the resistor is passing current and dissipating some of the transient energy.

For maximum absorption of the circuit opening transients, resistance should be small and capacitance should be large. Good representative values are R = 1/5 load resistance and C = 0.25 μF.

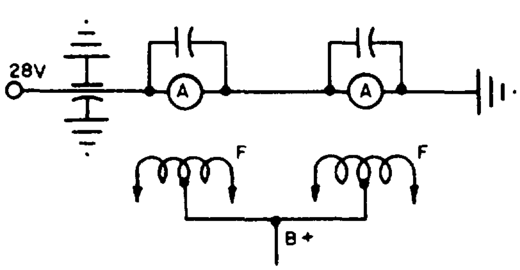

Figure 10-7.-Capacitive filtering of a servomotor.

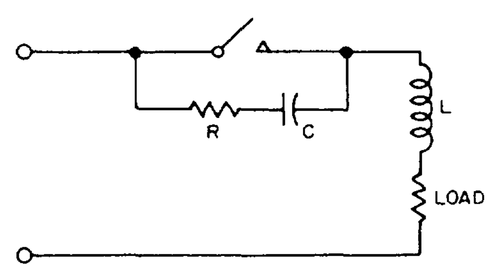

Figure 10-8.-An RC filter connected across a switch.

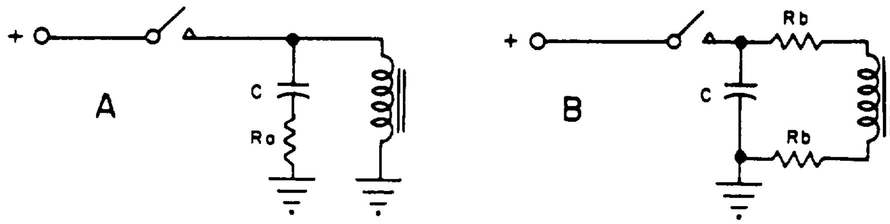

Figure 10-9.-Methods for using RC filters in relay circuits.

Figure 10-9 shows two RC filters used to absorb the transient interference resulting from the opening of a relay field. In circuit A, the value of Ra should be low enough to provide a resistance path to ground less than the line impedance and high enough to lower the Q sufficiently. The capacitor should be at least 0.25 µF with a voltage rating several times the lone voltage. Circuit B has the advantages of reducing the capacitor and coil leads to absolute minimum and reducing the relay field current. It has the disadvantage of carrying the dc coil current. Normal values of each resistance (Rb) in circuit B is 5 percent of the dc resistance of the coil. The capacitor is normally 0.25 µF. Circuit B serves as both a damping load and a high-loss transmission line.

INDUCTIVE-CAPACITIVE FILTERS

Filtering of radio interference is done by means of an inductor inserted in series with the ac power source. The inductor offers negligible impedance to the ac or power-line frequency and an increasingly high impedance to transient interference as frequency is increased. Combinations of inductance and capacitance are widely used to reduce both broadband and narrow-band interference.

Filters used to reduce radio interference transmissions are available in the Navy supply system. The filters come in a large variety of types and sizes. Filters are classified as to their frequency characteristics-namely, low-pass, high-pass, bandpass, and band-reject filters.

Filters are also classified as to their applications-namely, power-line, antenna, and audio filters. The type most often used in aircraft is the low-pass, power-line filter.

Low-Pass Filters

A low-pass filter is used in an aircraft to filter power leads coming from interference sources. The filter prevents the transmission of interference voltages into the wiring harness, and blocks transmission or reception of radio-frequency energy above a specified frequency.

The ideal low-pass filter has no insertion loss at frequencies below its cutoff frequency, but has an infinite insertion loss at all higher frequencies. Practical filters fall short of the ideal in three ways. First, a filter of acceptable physical size and weight has some insertion loss, even under dc conditions. Second, because of the lack of a pure inductor, the transition from low to high impedance is gradual instead of abrupt. Third, the impedance is held to a finite value for the same reason. Figure 10-10 compares the insertion loss of a typical low-pass filter with that of the hypothetical ideal filter.

Figure 10-11 shows the arrangement and typical parameters of a low-pass filter that has a design cutoff frequency of 100 kHz. Inductor L must carry load current. It must be wound of wire large enough that Its dc insertion loss is negligible. Therefore, filters are rated as to maximum current. The capacitors C1

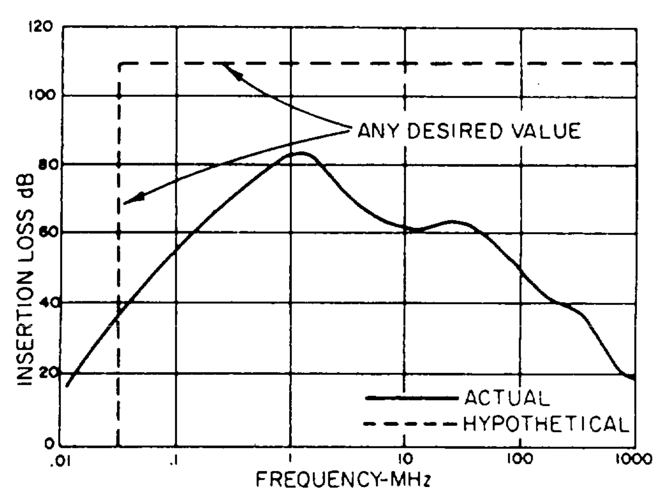

Figure 10-10.-Insertion loss curve of a low-pass power-line filter.

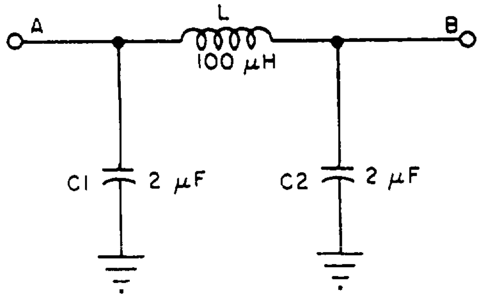

Figure 10-11.-Low-pass filter circuit.

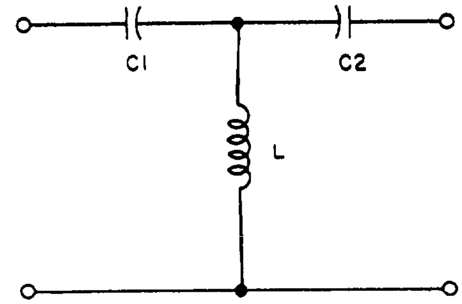

Figure 10-12.-Schematic diagram of a high-pass filter section.

and C2 must withstand the line voltage. Therefore, filters are also rated as to maximum voltage.

At frequencies immediately below cutoff, the filter looks capacitive to both the generator and the load. Inductive reactance X_L has very little influence, and no filtering action takes place. However, at frequencies above cutoff, the series reactance of coil L becomes increasingly higher. The series reactance of coil L is limited only by the resistance of the coil and its distributed capacitance. Coil L then functions as a high-frequency disconnect. The bypass values of both C1 and C2 become increasingly higher, and are limited only by the inductance of the capacitors and their leads. As a result of these two actions, high-frequency isolation between points A and B is achieved.

High-Pass Filters

In almost all radio transmitters operating at high frequencies (HF) and above, the master oscillator signal is generated at a submultiple of the output frequency. By use of one or more frequency multipliers, the basic oscillator frequency is raised to the desired output frequency. At the input to the antenna, an overdriven output amplifier may output the output frequency and harmonics of the output frequency. A high-pass filter is very effective in preventing the undesired harmonics from reaching the antenna and being radiated.

High-pass filters are also useful for isolating a high-frequency receiver from the influence of energy of signals of lower frequencies. Figure 10-12 shows a typical high-pass filter being used to reduce radio-noise interference. In symmetrical high-pass filter sections ($Z_{in} = Z_{out}$), the series combination of C1 and L should resonate at $\sqrt{2}$ times the desired cutoff frequency. The L/C ratio that is chosen should have a square root equal to the terminal impedance.

Bandpass Filters

Bandpass filters provide a very high impedance above and below a desired band of frequencies within that band. Bandpass filters find their greatest application in the following reamer:

- Decoupling the receiver from shock and overload by transmitters operating above and below the receiver band

- Multiplexing and decoupling two or more receivers or transmitters using the same antenna

A bandpass filter can be one of many forms and configurations, depending upon its application. For filtering antennas, a bandpass filter normally consists of one or more high-pass filter sections, followed by one or more low-pass filter sections. The configuration of sections is normally selected so the upper limit of the pass band approaches or exceeds twice the frequency of the lower limit of the pass band. Figure 10-13 shows typical arrangements for bandpass filters.

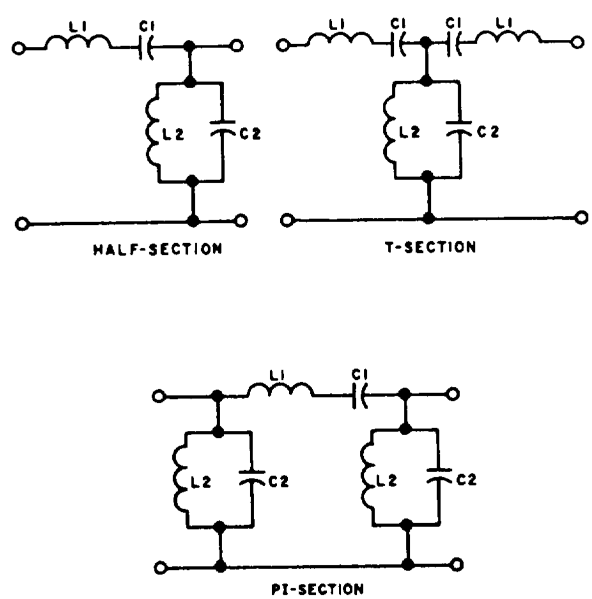

Figure 10-13.-Examples of bandpass filter circuits.

Band-Rejection Filters

A band-rejection (band-stop) filter is used to reject or block a band of frequencies from being passed. This filter allows all frequencies above and below this band to be passed with little or no attenuation.

The band-stop filter circuit consists of inductive and capacitive networks combined and connected to form a definite frequency response characteristic. The band-stop filter is designed to attenuate a specific frequency band and to permit the passage of all frequencies not within this specific band. The frequency range over which attenuation or poor transmission of signals occurs is called the "attenuation band." The frequency range over which the passage of signals readily occurs is called the "bandpass." The lowest frequency at which the attenuation of a signal starts to increase rapidly is known as the lower cutoff frequency. The highest frequency at which the attenuation of a signal starts to increase rapidly is known as the upper cutoff frequency. The basic configurations into which the band-reject filter elements can be arranged or assembled are known as the L- or half-section, the T-section, and the Pi-section configurations. These configurations are shown in figure 10-14. For a more in-depth discussion on the various filters discussed in this chapter, you should refer to NAVSHIPS 0967-000-0120, (EIMB), section 4.

BONDING

Learning Objective: *Identify purposes and techniques of bonding.*

Aircraft electrical bonding is defined as the process of obtaining the necessary electrical conductivity between all the metallic component parts of the aircraft. Bonding successfully brings all items of empennage and internal conduction objects to essentially the same dc voltage level appearing on the basic structure of the fuselage. However, bonding for radio frequencies is not quite so simple. Only direct bonding between affected components can accomplish the desired results at all frequencies. Only when direct bonding is impossible or operationally impracticable should bonding jumpers be used. Regardless of its dc resistance, any length of conductor has inductive reactance that increases directly with frequency. At a frequency for which the length of a bond is a quarter wavelength, the bond becomes a high impedance. The impedance of such a resonant lead becomes greater without limit as the dc resistance becomes lower. Multiple bonding using the same length of bonding jumper increases the impedance at the resonant frequency, but also tends to sharpen the high-impedance area around the resonant frequency. This sharpening is done by the rapid fall of impedance on each side of resonance.

PURPOSES OF BONDING

Bonding must be designed and executed to obtain the following results:

- Protect the aircraft and personnel from hazards associated with lightning discharges
- Provide power-current and fault-current return paths
- Provide sufficient homogeneity and stability of conductivity for RF currents affecting transmission and reception
- Prevent development of ac potentials on conducting frames, enclosures, cables of electrical and electronic equipment, and on conducting objects adjacent to unshielded transmitting antenna lead-ins

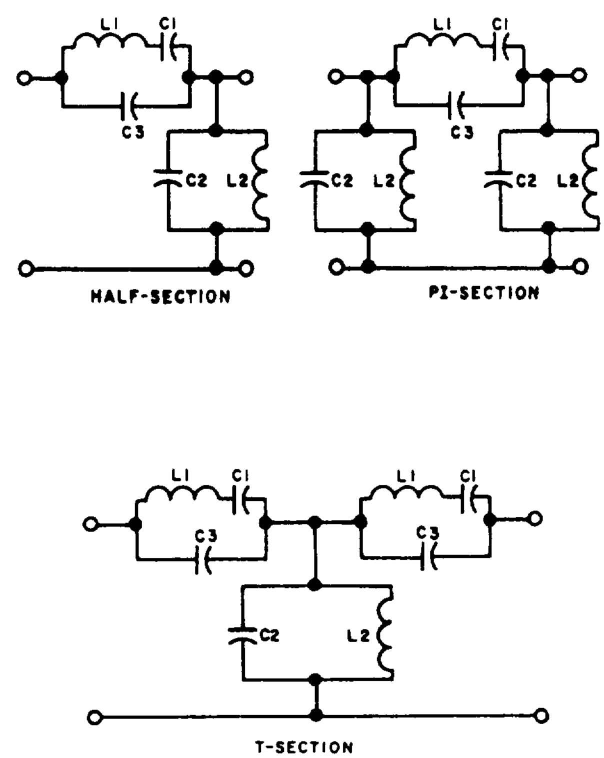

Figure 10-14.-Examples of band-reject filter circuits

- Protect personnel from the shock hazard resulting from equipment that experiences an internal power failure

- Prevent the accumulation of static charges that could produce radio interference or be an explosion hazard due to periodic spark discharge

BONDING FOR LIGHTNING PROTECTION

Close-riveted skin construction that divides any lightning current over a number of rivets is considered adequately bonded to provide a lightning discharge current path. Control surfaces and flaps should have a bonding jumper across each hinge. To protect the control cables and levers, additional jumpers should be connected between the control surface and the structure. The length of a discharge path through the control system should be at least 10 times the length of the path of the jumper or jumpers.

All external electrically isolated conducting objects (except antennas) should have a bonding jumper to the aircraft to ensure a low-impedance path. This is done so the voltage drop developed across the jumper system by the lightning discharge is minimized. The bonding jumpers must be kept as short as possible. When practical, a bonding jumper should not exceed 3 inches.

ELECTROSTATIC DISCHARGE

Learning Objective: *Recognize the hazards to electrostatic discharge-sensitive devices, to include proper handling and packaging techniques.*

The sensitivity of electronic devices and components to electrostatic discharge (ESD) has recently become clear through use, testing, and failure analysis. The construction and design features of current microtechnology have resulted in devices being destroyed or damaged by ESD voltages as low as 20 volts. The trend in this technology is toward greater complexity, increased packaging density, and thinner dielectrics between active elements. This trend will result in devices even more sensitive to ESD.

Various devices and components are susceptible to damage by electrostatic voltage levels commonly generated in production, test, operation, and by maintenance personnel. The devices and components include the following:

- All microelectronic and most semiconductor devices, except various power diodes and transistors

- Thick and thin film resistors, chips and hybrid devices, and crystals

All subassemblies, assemblies, and equipment containing these components/devices without adequate protective circuitry are ESD sensitive (ESDS).

You can protect ESDS items by implementing simple, low-cost ESD controls. Lack of implementation has resulted in high repair costs, excessive equipment downtime, and reduced equipment effectiveness.

The operational characteristics of a system may not normally show these failures. However, under internal built-in-test monitoring in a digital application, they become pronounced. For example, the system functions normally on the ground; but, when placed in an operational environment, a damaged PN junction might further degrade, causing its failure. Normal examination of these parts will not detect the damage unless you use a curve tracer to measure the signal rise and fall times, or check the parts for reverse leakage current.

STATIC ELECTRICITY

Static electricity is electrical energy at rest. Some substances readily give up electrons while others accumulate excessive electrons. When two substances are rubbed together, separated or flow relative to one another (such as gas or liquid over a solid), one substance becomes negatively charged and the other positively charged. An electrostatic field or lines of force emanate between a charged object to an object at a different electrostatic potential or ground. Objects entering this field will receive a charge by induction.

The capacitance of the charged object relative to another object or ground also has an effect on the field. If the capacitance is reduced, there is an inverse linear increase in voltage, since the charge must be conserved. As the capacitance decreases, the voltage increases until a discharge occurs via an arc.

Causes of Static Electricity

Generation of static electricity on an object by rubbing is known as the *triboelectric effect*. The following is a list of substances in the triboelectic series. The list is arranged in such an order that when any two substances in the list contact one another and then separate, the substance higher on the list assumes a positive charge.

Acetate

Glass

Human hair

Nylon

Wool

Fur

Aluminum

Polyester

Paper

Cotton

Wood

Steel

Acetate fiber

Nickel, copper, silver

Brass, stainless steel

Rubber

Acrylic

Polystyrene foam

Polyurethane foam

Saran

Polyethylene

Polypropylene

PVC (vinyl)

KEL F

Teflon®

The size of an electrostatic charge on two different materials is proportional to the separation of the two materials. Electrostatic voltage levels generated by nonconductors can be extremely high. However, air will slowly dissipate the charge to a nearby conductor or ground. The more moisture in the air, the faster a charge will dissipate. Table 10-1 shows typical measured charges generated by personnel in a manufacturing facility. Note the decrease in generated voltage with the increase in humidity levels of the surrounding air.

Table 10-1.-Typical Measured Electrostatic Voltages

MEANS OF STATIC GENERATION	VOLTAGE LEVELS @ RELATIVE HUMIDITY	
	LOW 10-20%	HIGH 65-90%
WALKING ACROSS CARPET	35,000	1,500
WALKING OVER VINYL FLOOR	12,000	250
WORKER AT BENCH	6,000	100
VINYL ENVELOPES FOR WORK INSTRUCTIONS	7,000	600
COMMON POLY BAG PICKED UP FROM BENCH	20,000	1,200
WORK CHAIR PADDED WITH URETHANE FOAM	18,000	1,500

Effects of Static Electricity

The effects of ESD are not recognized. Failures due to ESD are often misanalyzed as being caused by electrical overstress due to transients other than static. Many failures, often classified as other, random, unknown, etc., are actually caused by ESD. Misclassification of the defect is often caused by not performing failure analysis to the proper depth.

COMPONENT SUSCEPTIBILITY

All solid-state devices, except for various power transistors and diodes, are susceptible to damage by discharging electrostatic voltages. The discharge may occur across their terminals or through subjection of these devices to electrostatic fields.

LATENT FAILURE MECHANISMS

The ESD overstress can produce a dielectric breakdown of a self-healing nature when the current is unlimited. When this occurs, the device may retest good, but contain a hole in the gate oxide. With use, metal will eventually migrate through the puncture, resulting in a shorting of this oxide layer.

Another structure mechanism involves highly limited current dielectric breakdown from which no apparent damage is done. However, this reduces the voltage at which subsequent breakdown occurs to as low as one-third of the original breakdown value. ESD damage can result in a lowered damage threshold at which a subsequent lower voltage ESD will cause further degradation or a functional failure.

ESD ELIMINATION

The heart of an ESD control program is the ESD-protected work area and ESD grounded work station. When you handle an ESD-sensitive device outside of its ESD protective packaging, you need to provide a means to reduce generated electrostatic voltages below the levels at which the item is sensitive. The greater the margin between the level at which the generated voltages are limited and the ESDS item sensitivity level, the greater the probability of protecting that item.

PRIME GENERATORS

All common plastics and other generators should be prohibited in the ESD protected work area. Carpeting should also be prohibited. If you must use carpet, it should be of a permanently antistatic type. Perform weekly static voltage monitoring where carpeting is in use.

PERSONAL APPAREL AND GROUNDING

An essential part of the ESD program is grounding personnel and their apparel when handling ESDS material. Means of doing this are described in this section.

Smocks

Personnel handling ESDS items should wear long sleeve, ESD-protective smocks, short sleeve shirts or blouses, and ESD-protective gauntlets banded to the bare wrist and extending toward the elbow. If these items are not available, use other antistatic material (such as cotton) that will cover sections of the body that could contact an ESDS item during handling.

Personnel Ground Straps

Personnel ground straps should have a minimum resistance of 250,000 ohms. Based upon limiting leakage currents to personnel to 5 milliamperes, this resistance will protect personnel from shock from voltages up to 125 volts RMS. The wrist, leg, or ankle bracelet end of the ground strap should have some metal contact with the skin. Bracelets made completely of carbon-impregnated plastic may burnish around the area in contact with the skin, resulting in too high an impedance to ground.

ESD-PROTECTIVE MATERIALS

There are two basic types of ESD-protective material—conductive and antistatic. Conductive materials protect ESD devices from static discharges and electromagnetic fields. Antistatic material is a nonstatic generating material. Other than not generating static, antistatic material offers no other protection to an ESD device.

Conductive ESD-Protective Materials

Conductive ESD-protective materials consist of metal, metal-coated, and metal-impregnated materials. The most common conductive materials used for ESD protection are steel, aluminum, and carbon-impregnated polyethylene and nylon. The latter two are opaque, black, flexible, heat sealable, electrically conductive plastics. These plastics are composed of carbon particles, impregnated in the plastic, that provide volume conductivity throughout the material.

Antistatic ESD-Protective Materials

Antistatic materials are normally plastic-type materials (such as polyethylene, polyolefin, polyurethane, and nylon) that are impregnated with an antistatic substance. This antistatic migrates to the surface and combines with the humidity in the air to form a conductive sweat layer on the surface. This layer is invisible, and although highly resistive, it is amply conductive to prevent the buildup of electrostatic charges by triboelectric methods in normal handling. Simply stated, the primary asset of an antistatic material is that it will not generate a charge on its surface. However, this material won't protect an enclosed ESD device if it comes into contact with a charged surface.

This material is of a pink tint—a symbol of its being antistatic. Antistatic materials are for inner-wrap packaging. However, antistatic trays, vials, carriers, boxes, etc., are not used unless components and/or assemblies are wrapped in conductive packaging.

Hybrid ESD-Protective Bags

Lamination of different ESD-protective material is available. This combination of conductive and antistatic material provides the advantage of both types in a single bag.

ESDS DEVICE HANDLING

The following are general guidelines applicable to the handling of ESDS devices:

- Make sure that all containers, tools, test equipment, and fixtures used in ESD-protected areas are grounded before and during use. This may be done either directly or by contact with a grounded surface.

- Personnel handling ESDS items must avoid physical activities that are friction-producing in the vicinity of ESDS items. Some examples are putting on or removing smocks, wiping feet, and sliding objects over surfaces.

- Personnel handling ESDS items must wear cotton smocks and/or other antistatically treated clothing.

- Avoid the use or presence of plastics, synthetic textiles, rubber, finished wood, vinyls, and other static-generating materials (table 10-1) where ESDS items are handled out of their ESD-protective packaging.

- Place the ESD-protective material containing the ESDS item on a grounded work bench surface to remove any charge before opening the packaging material.

- Personnel must attach personnel grounding straps to ground themselves before removing ESDS items from their protective packaging.

- Remove ESDS items from ESD-protective packaging with fingers or metal grasping tool only after grounding, and place on the ESD-grounded work bench surface.

- Make periodic electrostatic measurements at all ESD-protected areas. This assures the ESD-protective properties of the work station and all equipment contained have not degraded.

- Perform periodic continuity checks of personnel ground straps, ESD-grounded work station surfaces, conductive floor mats, and other connections to ground. Perform this check with a megohmmeter to make sure grounding resistivity requirements are met.

ESDS DEVICE PACKAGING

Before an ESDS item leaves an ESD-protected area, package the item in one of the following ESD protective materials:

- Ensure shorting bars, clips, or noncorrective conductive materials are correctly inserted in or on all terminals or connectors.

- Package ESDS items in an inner wrap, of type II material conforming to MIL-B-81705, and an outer wrap of type I material conforming to MIL-B-81 705. You may use a laminated bag instead of the above provided it meets the requirements of MIL-B-81705. Cushion-wrap the item with electrostatic-free material conforming to PPP-C-1842, type III, style A. Place the cushioned item into a barrier bag fabricated from MIL-C-131 and heat-seal closed, method 1A-8. Place the wrapped, cushioned, or pouched ESDS item in bags conforming to MIL-B-117, type I, class F, style I. Mark the packaged unit with the ESD symbol and caution as shown in figure 10-15.

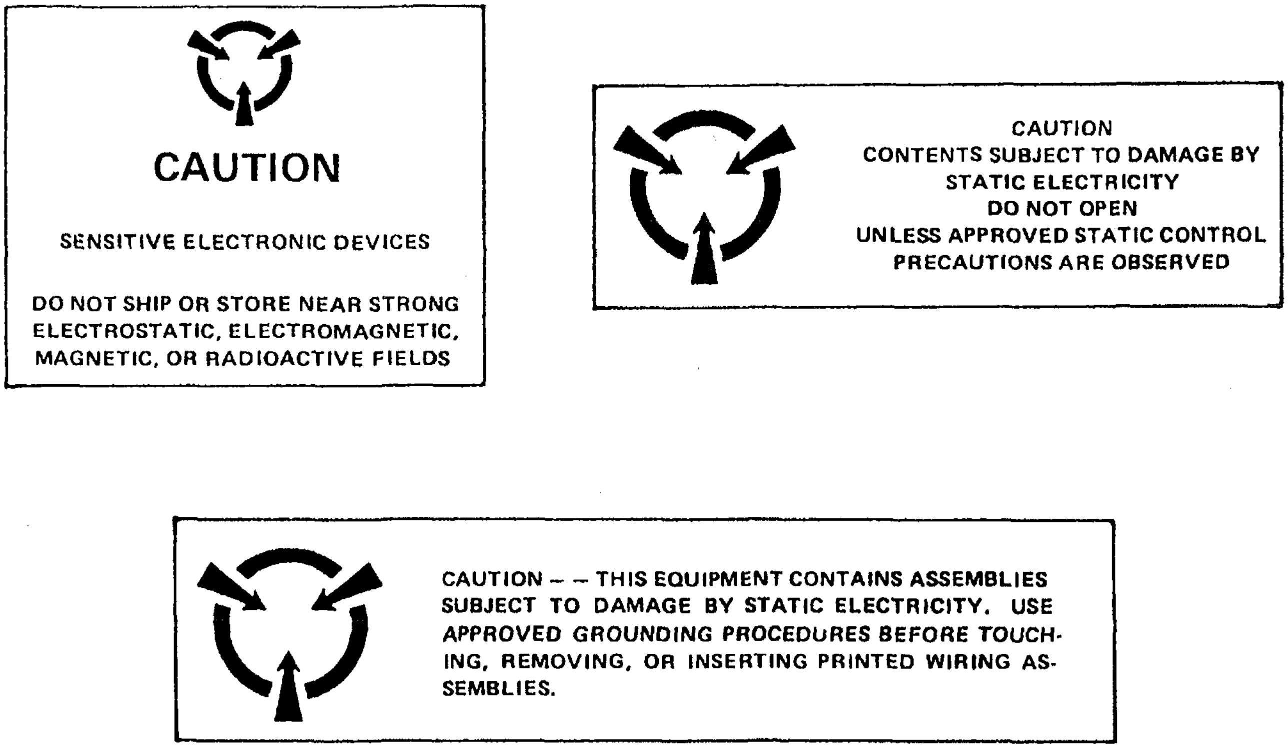

Figure 10-15.-ESDS markings.

REVIEW QUESTIONS

Q1. What causes internally generated noise in a receiver?

Q2. Atmospheric static produces what indication on a visual output device?

Q3. What is the definition of a nonlinear device?

Q4. What is the crossover frequency of a 4µF capacitor with 2-inch leads?

Q5. A bonding jumper should not exceed how many inches in length?

Q6. What problems can arise if the ESD program is not implemented?

Q7. What voltage level can be built up by walking across a carpet in low humidity?

Q8. What are the two types of ESD-protective material?